Coastal Engineering 87 (2014) 193–204

Contents lists available at ScienceDirect

Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng

Early warning and mass evacuation in coastal cities

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ARTICLE INFO

Article history:
Received 5 June 2013
Received in revised form 29 October 2013
Accepted 22 November 2013
Available online 10 January 2014

Keywords:
Early warning
Mass evacuation
Disaster management
Storm
Flood

ABSTRACT

The FP7 Theseus research project (2009–2013) aims to develop and assess innovative technologies and methodologies for coastal protection against erosion, flooding and environmental damages. While protection structures may help to reduce the level of hazard and the expected degree of loss, some danger of technical failures or human errors will always remain. For extreme events, the implementation of non-structural measures as early warning systems and disaster management practices is required to ensure the protection of population.

During Theseus, a methodology for helping the local authorities to prepare an action plan in case of coastal flooding was developed and tested on the estuary of Gironde in France. The methodology builds over the return of experience from past events and tries to clearly identify all the stages of an evacuation and the thinking process that can lead to a robust evacuation plan. It relies on a conceptual framework – SADT – which helps to understand how data should be processed from its collection to its use in the plan. The risk scenarios were calculated for current and future conditions of the XXIst century, taking into account the effects of climate change. The methodology is supported by the OSIRIS software, prototyped during the FP5 eponymous project and later distributed by CETMEF and the French basin authorities of Loire and Meuse.

The methodology for the preparation of evacuation plans was applied on a pilot city of Theseus, Bordeaux on the estuary of Gironde (France), and the software used to calculate evacuation times was tried out on Cesenatico near the Adriatic coast (Italy). This comparison verified the replicability of methodological guidelines in two different European contexts. The cultural and organizational differences and the different number of people involved underlined strong questions to be addressed when applying them. In order to assess the efficiency of an evacuation strategy and to compute the number of people successfully evacuated over time, a macroscopic model (not representing each individual vehicle but only flows of vehicles in congestion points) for the simulation of traffic congestion was used, based on the work of the University of Twente, Rijkswaterstaat and INFRAM. This model will be integrated in the Theseus decision support system for helping coastal managers to select their strategy for risk mitigation.

1. Introduction

One of the biggest challenges coastal regions will have to face in the next century is to cope with the broadly-acknowledged consequences of climate change. If the causes and details of those changes are not fully understood yet, meteorological and ocean observations over the past decades show that the water levels are rising at an increasing rate, with respect to the rise of temperatures in the atmosphere. Even if there is no such clear trend in the frequency or intensity of coastal storms yet, the sole rise of water levels will lead to more flood events if the protection structures are kept to the same level as today.

Coping with climate change is the main purpose of the Theseus FP7 project which aims at proposing innovative ways of mitigating the consequences of coastal risks. Those issues can be tackled at three levels: a traditional way of thinking in which we try to reduce the hazard by putting up new protection structures along our coasts or designing new buildings more resistant to the flood; a better long-term risk-aware spatial planning in which the hazard is quantified and helps to establish a spatial planning strategy that will reduce the vulnerability of coastal population; or the last option which supplements all other measures when the event could not be prevented: the

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0378-3839/$ – see front matter
http://dx.doi.org/10.1016/j.coastaleng.2013.11.015

improvement of emergency management in order to better provide for the safety of population. To be efficient, this latter option requires proactive actions to raise awareness of the risk among the population.

This article deals with the topic of mass evacuation in the context of coastal flooding. Mass evacuation greatly contributes to improving the resilience of a coastal city by protecting the people and stakes in it. However, a badly-prepared and implemented evacuation can lead to more damages than the ones directly caused by the disaster. Therefore, long before the disaster actually strikes, decision makers have to think about its physical consequences on the territory, to evaluate when an evacuation becomes necessary and how it can be implemented safely. In the framework of Theseus, a methodology was proposed to help this decision and is supported by a software tool used to assess the safety of a preventive evacuation. This result was proposed as a new social mitigation measure against coastal floods and is included in the final decision support tool made by the project. The product of the methodology, the evacuation plan, is meant to be disseminated among the population as well as shared between local authorities responsible for emergency management.

The first section describes the general issues of early warning and mass evacuation applied to the coastal territories with their particularities. A general methodology for the preparation of an action plan including mass evacuation is then proposed. Finally, the tool is applied and validated on two pilot sites of Theseus: in the Gironde estuary in France and partially in Cesenatico (Italy).

2. Early warning and mass evacuation for coastal cities prone to submersion

2.1. Definition of the evacuation problem—Context and hypothesis

The work presented here aims at better preventing and managing the risk for people living in coastal urban areas prone to submersion through a preventive mass evacuation. The typical case we are dealing with is a major coastal submersion of a city on the Atlantic coast of Western Europe, caused by a combination of high tide, strong wind and waves (maritime storm). In the future, this kind of exceptional event and sea level rise can be worsened by the long-term consequences of climate change, and we integrate this factor in the possible scenarios to the maximum extent of sea level rise by 1 m (IPCC, 2007).

The key issue is to identify the crisis management plan that will save most lives when implemented in advance and given the data and resources that are available in the vigilance and pre-alert phases. In that perspective, our proposal endeavors to answer these two fundamental issues:

1. How to elaborate submersion scenarios and optimized evacuation plans in the preparation phase, e.g. outside any event?
2. How to support the implementation and management of the evacuation on the ground?

Another issue is raised before the actual implementation of the evacuation on the ground: how to interpret the forecast and other real-time data to support the decision to evacuate or not (and which zones in priority) during the vigilance and alert phase? While this is not the main topic of this paper, another work started on this topic and is briefly described in Section 3.4.3.

The major assumption is that a coastal submersion due to severe conditions can generally be rather accurately anticipated at least 24 h in advance thanks to the forecast. This forecast (see Section 2.2) is generally made with numerical models and is the first triggering factor which let authorities and population anticipate the disaster and correctly organize the evacuation.

Nevertheless, for large submersion events where a large part of the territory is flooded and numerous lives are threatened, this delay is not sufficient to improvise an evacuation plan, which is both very complex and risky. Such plans have to be prepared in advance because they require a lot of expertise, data and a strong collaboration between the different actors of crisis management and the general public. Lindell et al. (2007) highlight that evacuation policies provide knowledge about safe places to go and a safe route to travel, but they have to be addressed in advance by increasing local training and participation.

This preparation is required but never guarantees a successful emergency management because scenarios prepared do not describe all possible situations and managers still have to adapt to the real situation on the ground (see return of experience in fpar-national-guidelines).

2.2. Forecast and early warning for coastal and estuarine cities

Forecasting coastal or estuarine submersion proves to be more complex than river floods, especially because upstream parameters to take into account in models are more numerous. The global height of the sea which is finally considered to evaluate the submersion in case of the most severe events is the result of the addition of several cumulative factors: tide, waves, and storm surge due to wind and low pressures in the atmosphere (see the case of the Gironde estuary in Section 4).

In the framework of the Theseus project which studies adaptation strategies of coastal zones to climate change, additional parameters for prospective scenarios are sea level rise and changes in storm frequencies and intensities. Nevertheless, the proposals for evacuation planning and decision are supposed to be valid whatever the submersion scenarios and the parameters' values. The real challenge here is first to be able to characterize a limited set of representative scenarios for a given site and secondly to associate a real-time forecast (a set of parameters values) to one of the pre-defined and typical submersion and evacuation scenario as the starting point for evacuation decision and management (see Section 2.4).

2.3. Decision criteria and levers of action

The decision to evacuate is never easy because it is often difficult to evaluate its human, organizational and economic consequences. Accordingly, decision makers need clear indicators and a reference framework for implementation (Radwan et al., 2005). The evacuation process is complex and involves many different factors—all of which are potentially significant insofar as forgetting just one can hinder the execution of an evacuation plan or even cause it to fail. To illustrate this point, one can consider the fuel shortage issue reported by Litman (2006) after Hurricane Rita in the USA in 2005. It is therefore vital to identify all such factors – both positive and negative – and not lose sight of potential blockage points, such as people's reluctance to evacuate their home and network "domino effects" which can perturb or even stop flows of people or equipment (people blocked on the roads, preventing supplies from reaching confined people, etc.).

In the Netherlands, permanent flood risk from sea and strong historical events led to the adoption of evacuation as a full strategy for risk prevention in dike rings. The approach of evacuation planning is particularly well implemented because of the strong constraints laid by the need of the evacuation of an area as large as a dike ring (it is estimated that 11 million people live in dike rings vulnerable to serious flooding). Time is a critical factor in the evacuation process (Kolen and Helsloot, 2012). The timeline on Fig. 1 shows how time influences the efficiency of an evacuation. When the event is foreseen, the decision makers are faced to the choice of launching the evacuation or waiting for more accurate forecasts. However, the longer the decision to evacuate takes, the less time there is for the actual implementation of it, which leads to a dramatic decrease of its efficiency.

Therefore, a maximum number of relevant criteria must be taken into account and integrated in the scenarios, from the pre-alert phase to the return to normal. Nevertheless, the numerous technical criteria have to be analyzed, sorted, selected and finally grouped into synthetic indicators that have a sense for decision makers and managers. This work has been led both for the evacuation decision support method